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Steel composition and parts forged by a forging die

Description

The present invention relates to a new steel composition, die-formed parts produced therefrom, a method for producing the die-formed parts and their use as chassis parts for passenger cars and commercial vehicles.

Forged chassis components for motor vehicles are safety-relevant parts for which, apart from a high degree of strength, a high degree of toughness (characterized, e.g., by the characteristic values of elongation at fracture, contraction at fracture, notch impact strength) is required. Therefore, up into the 1980s, these components were subjected, nearly without exception, to an expensive and/or laborious final heat treatment (quenching and tempering) after hot forming. Then, in the 1980s, the "precipitation hardening ferritic-perlitic steels" ("Ausscheidungshärtende Ferritisch-Perlitische Stähle", AFP-Stähle) were developed, for which the characteristic strength values are reached without final heat treatment by precipitation of carbonitrides in the ferritic-perlitic steel matrix. Today, the use of these steels for forged steel components for chassis parts for passenger cars is the rule. In the processing of these steels it is important to adjust the temperature control such that the conversion of the steels and the precipitation of the carbonitrides are optimally matched to each other.

In commercial vehicles, safety-relevant chassis parts such as axle legs are, to this day, nearly exclusively produced from

quenched and tempered steels, that is, with the expensive and/or laborious final heat treatment. Following reasons may be mentioned for this:

A higher strain on the commercial vehicle parts and therefore a higher specified strength with, simultaneously, a higher required toughness of the material. In particular, the fulfilment of specifications is often required, which include notch impact strength values that are to be guaranteed. This is not possible with the precipitation hardening ferritic-perlitic steels of corresponding strength that are on the market today.

Due to their significantly higher mass, commercial vehicle parts cool down from the hot forming temperature distinctly differently from passenger car parts. As temperature control has crucial influence on the achievable mechanical characteristic values (see above), even the lower mechanical characteristic values that are usual for passenger car parts can mostly not be realized for commercial vehicle parts with the precipitation hardening ferritic-perlitic steels available today.

A direction of development in materials in the commercial vehicle sector pursued in the past years had the aim of achieving bainitic structural conditions by means of direct quenching and tempering of low carbon steels from the deformation heat without subsequent tempering, and thus of economizing on the expensive final quenching and tempering (see DE-PS 36 28 264 A1, DE-PS 41 24 704 A1, US-PS 5,660,648). In this technology, however, the low elastic ratio, the relatively low creep resistance and the inhomogeneity of properties as well as an increased propensity to become distorted, are problematic. It has not established itself in the area of safety-relevant chassis parts for commercial vehicles.

In the area of precipitation hardening "AFP"-steels with ferritic-perlitic structure, considerable development work was carried out with the aim of improving toughness, in order to be able to employ this group of steels also in the area of commercial vehicle chassises (see Hertogs, J.A., Ravenhorst, H; Richter, K.E.; Wolff, J.: Neuere Anwendungen der ausscheidungshärtenden ferritisch-perlitischen Stähle für geschmiedete Bauteile im Motor und Fahrwerk. Conference "Stahl im Automobilbau", Würzburg, 24-26 Sep. 1990; and Huchtemann, B.; Schüler, V.: Entwicklungsstand der ausscheidungshärtenden ferritisch-perlitischen (AFP-)Stähle mit Vanadium. Stahl 2/1992, p. 36-41). Slight improvements were thereby achieved, e.g. by lowering the forming temperature. However, since the mould filling performance is clearly inferior at lowered forming temperatures and furthermore tool wear drastically increases, this variant was not suitable for operational use.

A further variant focussed on titanium alloy additives for grain refining and thereby for improving toughness. The problem herein was that grain refining was achieved by titanium nitrides. The nitrogen required for an increase in toughness was thereby in bound form and thus not available. The consequence was a far inferior toughness in comparison to quenched and tempered steels.

The underlying problem of the invention is therefore to provide a steel composition for precipitation hardening ferritic-perlitic steels for the production of die-formed parts, which, without additional heat treatment, display a high degree of strength and simultaneously a high degree of toughness in these construction parts, so that they can be used as chassis parts also for commercial vehicles.

The problem is solved by a steel composition comprising the following components in % by weight:

C: 0.12-0.45
Si: 0.10-1.00
Mn: 0.50-1.95
S: 0.005-0.060
Al: 0.004-0.050
Ti: 0.004-0.050
Cr: 0-0.60
Ni: 0-0.60
Co: 0-0.60
W: 0-0.60
B: 0-0.01
Mo: 0-0.60
Cu: 0-0.60
Nb: 0-0.050
V: 0.10-0.40
N: 0.015-0.040

Remainder: Fe and unavoidable impurities

with the proviso that:

1) wt% V x wt% N = 0.0021 to 0.0120

2) 1.6x wt% S + 1.5x wt% Al + 2.4x wt% Nb + 1.2x wt% Ti = 0.035 to 0.140

3) 1.2x wt% Mn + 1.4x wt% Cr + 1.0x wt% Ni + 1.1x wt% Cu + 1.8x wt% Mo = 1.00 to 3.50

A central point of the invention is that the necessary improvement in toughness is achieved by a reduction in the carbon content of the steel in comparison to the concentrations usual today at a given level of strength. The loss in strength that is to be expected due to this measure according to the prior art is, according to the invention, not only completely eliminated but even overcompensated for by the particular combination of the remaining components.

Essential factors that are responsible for the high strength despite the lowering of the carbon content are in particular:

- A vanadium content of 0.10 wt% to 0.40 wt% and a nitrogen content of 0.015 wt% to 0.040 wt%, wherein the following condition is to be fulfilled according to the invention:

  wt% V x wt% N = 0.0021 to 0.0120;
  preferably wt% V x wt% N = 0.0028 to 0.0060.

- A balanced ratio of the micro-alloying elements Ti, Al and Nb with the sulphur, wherein the following condition is to fulfilled according to the invention:

  1.6x wt% S + 1.5x wt% Al + 2.4x wt% Nb + 1.2x wt% Ti = 0.035 to 0.140;

  preferably 1.6x wt% S + 1.5x wt% Al + 2.4x wt% Nb + 1.2x wt% Ti = 0.040 to 0.080.

- A balanced ratio of alloying elements that increase the strength of mixed crystals, wherein the following condition is to be fulfilled according to the invention:

  1.2x wt% Mn + 1.4x wt% Cr + 1.0x wt% Ni + 1.1x wt% Cu + 1.8x wt% Mo = 1.00 to 3.50;

  preferably 1.2x wt% Mn + 1.4x wt% Cr + 1.0x wt% Ni + 1.1x wt% Cu + 1.8x wt% Mo = 1.65 to 2.80

The above-mentioned steel composition is excellently suited to the production of die-formed parts that can be used as chassis parts such as axle legs for passenger cars or commercial vehicles.

The die-formed parts according to the invention are produced by a method comprising the following steps:

(a) heating the ingoing material made of a steel composition as defined above to a temperature of 1,000 to 1,300°C;

(b) forming the ingoing material of step (a) by forging;

(c) cooling the die-formed part obtained in step (b) to room temperature, wherein the cooling rate is at least 0.2°C/s in the temperature range down to 580°C.

The production method according to the invention is described in greater detail with regard to individual production steps in the following.

First, in a step (a), an ingoing material produced from the steel composition according to the invention, in a commercially available geometry, e.g. long steel, is heated to 1,000 to 1,300°C. The material is kept in this temperature range at least until a homogenous austenitic structure has formed. Usually the duration is 5 to 10 minutes. When the die-formed part is to be used as a chassis part for commercial vehicles it is preferred that the ingoing material have a mass of more than 15 kg. For die-formed parts that are to be used as chassis parts in passenger cars an ingoing material of a mass between 5 and 14 kg is usually utilized.

In step (b) the ingoing material, in a usual forming process, is formed by forging into the desired shape in one or more forming steps. Preferably, the forming process in step (b) takes place immediately after the heating of the ingoing material in step (a), so that the ingoing material has a temperature in the range of 950 and 1,250°C during its forming.

In step (c) the die-formed part obtained in step (b) is cooled to room temperature. Herein the cooling rate is at least 0.2°C/s until a temperature of 580°C.

By means of the cooling rate, the mechanical properties of the die-formed part can be adjusted in a defined manner according to requirements.

The cooling rate during cooling of the die-formed parts made of the steel according to the invention to 580°C is preferably chosen in the range from 0.2 to 6°C/s. More preferable is a cooling rate in the range of 0.2 to 0.6°C/s. This corresponds to the cooling of heavy commercial vehicle parts in resting air. This has the advantage that the die-formed parts for a commercial vehicle of step (b) can be cooled merely by standing in air.

Regarding the achievement of especially high strength and toughness values as are required for chassises for commercial vehicles, a rate of cooling to 580°C of 0.7°C/s to 6°C/s is especially preferred. The setting of a cooling rate in this range for commercial vehicle parts with a mass of more than 15 kg is achieved, e.g., by means of a water cooling stretch that is flexible with regard to the number of active water nozzles and their orientation as well as with regard to pressure and flow rate.

For the lighter passenger car parts made of the steel according to the present invention, the same connections between cooling rate and properties apply. Due to the lower mass of passenger car parts, accelerated cooling is, in contrast to the commercial vehicle parts, only required for setting the cooling rate when the cooling rate is to lie in the upper half of the given range. Cooling rates of about 0.7 to about 2.0°C/s occur automatically with mere cooling in resting air.

The cooling rate below 580°C can be chosen arbitrarily and has no influence with regard to strength and toughness of the obtained die-formed part.

The die-formed part produced according to the present invention displays the following mechanical properties after cooling from the forming heat:

- Tensile test according to DIN EN 10002 at room temperature:
  off-set yield strength: $Rp_{0.2} \geq 540$ MPa, preferably 540-850 MPa
  tensile strength: $Rm \geq 700$ MPa, preferably 700-1,100 MPa
  elongation at fracture: $A5 \geq 10$ %, preferably 10-16 %
  contraction at fracture: $Z \geq 20$ %, preferably 20-50 %

- Impact test on ISO-U samples according to DIN EN 50115:
  notched bar impact work: $Av(RT) \geq 30$ J, preferably 30-70 J
  notched bar impact work: $Av(-20°C) \geq 10$ J, preferably 10-25 J

A die-formed part produced according to the particularly preferred method can, depending upon the chosen cooling rate, display the following mechanical characteristic values:

$Rp_{0.2}$ = 580-680 MPa
Rm = 800-900 MPa
A5 = 14-16 %
Z = 35-50 %
Av(RT) = 30-40 J
Av(-20°C) = 10-20 J

Likewise, according to the particularly preferred method, die-formed parts with the following properties can be produced:

$Rp_{0.2}$ = 800-850 MPa
Rm = 1,050-1,100 MPa
A5 = 10-12 %
Z = 20-30 %

The above-mentioned properties make clear that the die-formed parts according to the present invention display a high degree of strength and simultaneously a high degree of toughness after cooling from the forming heat, in comparison to the prior art. Therefore, the die-formed parts according to the present invention can be used as safety-relevant chassis components such as axle legs for passenger cars and even for commercial vehicles.

The invention is explained in greater detail by means of the following examples.

Example 1

Use of a steel with the following chemical composition:

C:	0.14	wt%
Si:	0.40	wt%
Mn:	1.00	wt%
S:	0.020	wt%
Al:	0.035	wt%
Ti:	0.015	wt%
Nb:	0.005	wt%
Cr:	0.45	wt%
Ni:	0.10	wt%
Cu:	0.15	wt%
Mo:	0.10	wt%
V:	0.25	wt%
N:	0.030	wt%

Inductive warming of the bar steel with a cross section of 140 mm^2 to 1,250°C and keeping the steel at this temperature for 10 minutes.

Forging of the square bar material to an axle leg of 30 kg mass in a pre-upsetting operation, two finishing forming operations and a trimming operation. The temperature of the axle leg at the end of the forming process is 1,100°C.

Cooling of the axle leg from 1,100°C to 580°C on a cooling stretch at a cooling rate of 3,9°C/s.

The axle leg displays the following mechanical properties which are determined according to DIN EN 10002 at room temperature and DIN EN 50115:

$Rp_{0.2}$ = 580 MPa
Rm = 750 MPa
A5 = 16 %
Z = 55 %
Av(room temperature) = 50 J
Av(-20°C) = 20 J

Example 2

Use of a steel with the following chemical composition:

C:	0.37	wt%
Si:	0.40	wt%
Mn:	0.90	wt%
S:	0.035	wt%
Al:	0.015	wt%
Ti:	0.035	wt%
Nb:	0.010	wt%
Cr:	0.10	wt%
Ni:	0.50	wt%
Cu:	0.20	wt%
Mo:	0.10	wt%
V:	0.28	wt%
N:	0.032	wt%

Inductive heating of the bar steel with a cross section of 140 mm^2 to 1,250°C and keeping the steel at this temperature for 10 minutes.

Forging of the square bar material to an axle leg of 38 kg mass in a pre-upsetting operation, two finishing forming operations and a trimming operation. The temperature of the axle leg at the end of the forming process is 1,150°C.

Cooling of the axle leg from 1,150°C to 580°C in resting air at a cooling rate of 0.5°C/s.

The axle leg displays the following mechanical properties, which are determined at room temperature according to DIN EN 10002:

$Rp_{0.2}$ = 700 MPa
Rm = 1,000 MPa
A5 = 12 %
Z = 30 %

Example 3

Use of a steel according to example 2.

Heating and forming of the axle leg weighing 38 kg according to example 2.

Cooling of the axle leg from 1,150°C to 580°C on a cooling stretch at a cooling rate of 1.8°C/s.

The axle leg displays the following mechanical properties, which are determined at room temperature according to DIN EN 10002:

$Rp_{0.2}$ = 820 MPa

Rm = 1,080 MPa

A5 = 10 %

Z = 20 %